Maize Journal (October 2026) 15(2): 101-108

RESEARCH PAPER

Synergistic effects of legume intercropping and integrated pest management on fall armyworm management in maize

Nikita Talukdar • Jeti Konsam

Abstract: An experiment was carried out at the Agricultural Research Farm, Andro, Central Agricultural University, Imphal, Manipur during *kharif* 2025 to study the impact of intercropping of maize with legumes along with seed treatment and biopesticide spray against fall armyworm (*Spodoptera frugiperda*) and productivity of maize. A randomized block design with three replications was employed to test the effect of eight treatments, which included chlorantraniliprole seed treatment, intercropping with ricebean or rajma, and foliar spray of *Bacillus thuringiensis*, alone or in combination. Infestation increased progressively up to 50 days after planting (58.00% in untreated sole maize) before decreasing towards maturity of the crop. Intercropping of ricebean along with chlorantraniliprole seed treatment and foliar spray of *Bt* at 25-30 DAG showed the minimum infestation and leaf damage, the highest population of natural enemies (6.10 per plant), the lowest cob damage rating (1.11), the highest grain yield and intercrop yield with 54.81 q ha^{-1} and 6.14 q ha^{-1} respectively and the highest B:C ratio (3.17), as compared to untreated sole maize, which recorded the highest infestation (58.00%), the lowest natural enemy population (2.03 per plant), the highest cob damage rating (3.89), the lowest grain yield (27.78 q ha^{-1}) and the lowest B:C ratio (0.61). Legume intercropping on its own accounted for reduced pest infestation and increased natural enemy activity in comparison with sole cropping, but the integration of legume intercropping, seed treatment, and application of biopesticides resulted in additive pest suppression and enhanced biological control. The integrated use of ricebean intercropping, chlorantraniliprole seed treatment, and *Bt* foliar spray can be used as an alternative approach to manage lepidopteran pests on maize.

Keywords: *Zea mays* • *Spodoptera frugiperda* • Intercropping • Legume • *Bacillus thuringiensis*

Introduction

Maize (*Zea mays* L.) ranks third after rice and wheat in importance as a cereal crop, and is one of the crops having the highest genetic yield potential and is utilized for food, feed and industrial purposes (Dass *et al*., 2018; Malhotra, 2017). In terms of production, the USA, China and Brazil are the major producer countries, contributing to nearly two-thirds of the world's maize production, but on the other hand, India ranks fourth in maize area production while ranking seventh in terms of production amounting to about 4% of the world's maize area (Vatta *et al*., 2023). According to the reports of 2023-24, the production of maize stood at 37.67 million tons with an average yield of 3.35 t/ha (Directorate of Economics and Statistics, 2024), and in the state of Manipur, the area under maize production was reported to be 27,990 ha with an average yield of 2.38 t/ha (Government of Manipur, 2023).

Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is an exotic pest of American origin reported for the first time in India in May 2018 in Shivamogga district, Karnataka (Sharanabasappa *et al*., 2019), and has now been found to spread throughout the maize growing areas of the country. This pest feeds on

✉ Jeti Konsam: jtkonsam@gmail.com

Department of Entomology, College of Agriculture, Central Agricultural University, Imphal-795004, Manipur, India

Received: 21 August 2026/ Accepted: 22 October 2026

© Maize Technologists Association of India 2026

the foliage, whorl, and developing ears at all plant growth stages, causing a loss of 8.3-20.6 million tonnes per annum (Mallapur *et al*., 2018). Maize-legume intercropping is one such cultural method widely recognized as decreasing lepidopteran pest pressure. The strategy of intercropping can be applied in combination with complementary chemical and biological control measures for season-long protection from fall armyworm (Hailu *et al*., 2018). The impact of intercropping of maize and legumes with seed treatment of chlorantraniliprole and foliar spray of *Bt* on percentage plant infestation, leaf damage rating of *S. frugiperda* and natural enemies population and cob damage rating of *S. frugiperda* was assessed in the present study.

Materials and methods

Experimental site and soil

The present experiment was conducted at the Agricultural Research Farm, Andro, Central Agricultural University, Imphal, Manipur, India, lying at 24°25′N latitude and 93°56′E longitude at an altitude of 790 m above mean sea level, during *kharif* 2025. The experimental site has clay loam soil with a pH of 5.5.

Experimental design and treatments

Maize (cv. HQPM-5) was sown on 31st July 2025 in a randomized block design with eight treatments replicated three times, in plots of 3 m × 3 m spaced 60 cm × 25 cm, with maize and the legume intercrop planted in a 1:1 row ratio. The treatment details are presented in Table 1.

Table 1. Treatment details

Treatment No.	Treatment details
T_1	Seed treatment (Chlorantraniliprole 600 FS @ 5.6 ml/ kg seed) + Maize + Ricebean (1:1)
T_2	Seed treatment (Chlorantraniliprole 600 FS @ 5.6 ml/ kg seed) + Maize + Rajma (1:1)
T_3	Seed treatment (Chlorantraniliprole 600 FS @ 5.6 ml/ kg seed) + Maize + Ricebean + Foliar spray with *Bacillus thuringiensis* formulation at 25-30 DAG
T_4	Seed treatment (Chlorantraniliprole 600 FS @ 5.6 ml/ kg seed) + Maize + Rajma + Foliar spray with *Bacillus thuringiensis* formulation at 25-30 DAG
T_5	Maize + Ricebean
T_6	Maize + Rajma
T_7	Sole maize with farmer's practice
T_8	Sole maize without any treatment

Crop establishment and agronomic management

Maize seeds (HQPM-5) were obtained from the Indian Institute of Maize Research, whereas the local legumes used in the present study - ricebean (Chak Hawai) and rajma (Rajama) were procured from local markets. All recommended agronomic management practices for maize cultivation were followed, except for the different pest management interventions specified under each treatment.

Observations recorded

Percent plant infestation

The percent plant infestation due to *Spodoptera frugiperda* was recorded at 10-day intervals, starting from the day of first observation until harvest maturity. The number of infested plants was recorded from 50 randomly tagged plants per plot and percent plant infestation was calculated as:

$$\text{Percent plant infestation} = \frac{\text{No. of infested plants}}{\text{Total No. of plants observed}} \times 100$$

Leaf damage rating

The extent of leaf damage inflicted by the larvae was assessed on five randomly selected plants per plot at the same 10-day intervals. Leaf damage caused by *S. frugiperda* was scored on the 1-9 visual rating scale of Davis and Williams (1992), ranging from no visible damage (1) to complete defoliation with long lesions on most leaves (9).

Natural enemy population

The population of natural enemies was recorded in each plot at 10-day intervals, starting from the date of first infestation until harvest of the crop.

Cob damage rating

The extent of cob damage caused by *S. frugiperda* was recorded at harvest on three randomly chosen cobs in

each plot. Cob damage severity was recorded according to the cob damage scale of Davis and Williams (1992).

Statistical analysis

Data expressed as percentages for plant infestation were arc-sine transformed prior to statistical analysis. Data were analysed using ANOVA for a randomized block design in Microsoft Excel and means were compared using Duncan's Multiple Range Test (DMRT) at the 5 per cent level of significance (Gomez and Gomez, 1984).

Results

Percent plant infestation due Spodoptera frugiperda

The infestation levels of *S. frugiperda* in plants progressively increased up to 50 DAI (Days after infestation), reaching the maximum for the season, before gradually reducing up to 100 DAI in all treatments (Table 2). Infestation at 10 DAI varied from 13.33% in T_3 to 22.67% in T_8. At the 50 DAI peak, the highest infestation (58.00%) was recorded in T_8, significantly higher than other treatments, followed by T_7 (52.67%). The lowest infestation (31.33%) was recorded in T_3, followed by T_4 (35.33%). Intermediate infestation (45.33% and 50.67%, respectively, at 50 DAI) was recorded in the intercropped-only treatments (T_5 and T_6), while significantly higher infestation was recorded in the sole maize treatments (T_7, T_8) than in the seed-treated intercropped treatments (T_1-T_4). At 100 DAI, infestation ranged from 18.67% (T3) to 40.67% (T_8). T_3 (chlorantraniliprole seed treatment + ricebean intercrop + *Bt* foliar spray) consistently recorded the lowest fall armyworm infestation throughout the crop season.

Leaf damage rating due to Spodoptera frugiperda

The leaf damage rating (LDR) due to *S. frugiperda* increased gradually from 10 DAI to a peak at 50 DAI, after which it decreased with crop maturity (Table 3). At 10 DAI, LDR ranged from 2.27 (T_3) to 3.73 (T_8). The highest LDR at 50 DAI occurred in T_8 (6.13), T7 (5.93), T_6 (5.80) and T_5 (5.47), while the lowest LDR was observed in T_3 (4.07) and T_4 (4.60). Across all sampling periods, T_3 recorded the lowest LDR, with a minimum of 1.93 at 100 DAI, compared with a minimum of 3.46 at 100 DAI for T_8. This was attributed to the cumulative effect of the physical/olfactory barrier provided by the ricebean intercrop, systemic protection from

Table 2. Mean percent plant infestation due to *Spodoptera frugiperda* in maize at 10-day intervals

Treatment	10 DAI	20 DAI	30 DAI	40 DAI	50 DAI	60 DAI	70 DAI	80 DAI	90 DAI	100 DAI	Mean
T_1	14.00 (21.94)^{ab}	19.33 (26.08)^{a}	26.67 (31.09)^{ab}	32.67 (34.85)^{b}	36.67 (37.24)^{b}	34.00 (35.65)^{bc}	30.00 (33.18)^{ab}	27.33 (31.50)^{ab}	24.67 (29.78)^{ab}	22.00 (27.96)^{ab}	26.73 (27.96)
T_2	16.00 (23.55)^{bc}	22.00 (27.96)^{ab}	29.33 (32.79)^{bc}	34.67 (36.05)^{bc}	39.33 (38.83)^{b}	38.00 (38.04)^{cd}	34.00 (35.65)^{bc}	30.67 (33.61)^{bc}	27.33 (31.46)^{bc}	24.67 (29.76)^{bc}	29.60 (29.76)
T_3	13.33 (21.37)^{a}	18.67 (25.55)^{a}	22.67 (28.43)^{a}	27.33 (31.52)^{a}	31.33 (34.04)^{a}	28.00 (31.92)^{a}	26.67 (31.04)^{a}	23.33 (28.85)^{a}	20.67 (27.03)^{a}	18.67 (25.59)^{a}	23.07 (25.59)
T_4	16.67 (24.09)^{cd}	21.33 (27.49)^{ab}	25.33 (30.22)^{ab}	30.00 (33.20)^{ab}	35.33 (36.46)^{ab}	31.33 (34.04)^{ab}	29.33 (32.79)^{ab}	26.00 (30.65)^{ab}	23.33 (28.88)^{ab}	21.33 (27.50)^{ab}	26.00 (27.50)
T_5	18.67 (25.59)^{de}	24.67 (29.78)^{bc}	32.67 (34.86)^{c}	39.33 (38.84)^{cd}	45.33 (42.32)^{c}	41.33 (40.01)^{d}	38.67 (38.45)^{cd}	35.33 (36.46)^{cd}	32.00 (34.43)^{cd}	28.67 (32.35)^{c}	33.67 (32.35)
T_6	19.33 (26.04)^{ef}	25.33 (30.21)^{bc}	33.33 (35.26)^{c}	42.67 (40.78)^{de}	50.67 (45.38)^{d}	48.00 (43.85)^{e}	42.67 (40.78)^{de}	39.33 (38.83)^{de}	36.00 (36.87)^{de}	33.33 (35.26)^{d}	37.07 (35.26)
T_7	21.33 (27.50)^{fg}	28.00 (31.92)^{cd}	38.00 (38.05)^{d}	46.67 (43.08)^{ef}	52.67 (46.53)^{d}	51.33 (45.77)^{ef}	46.67 (43.09)^{ef}	42.00 (40.39)^{ef}	39.33 (38.84)^{ef}	36.67 (37.26)^{de}	40.27 (37.26)
T_8	22.67 (28.43)^{g}	30.67 (33.61)^{d}	44.00 (41.54)^{e}	51.33 (45.76)^{f}	58.00 (49.61)^{e}	55.33 (48.07)^{f}	51.33 (45.76)^{f}	47.33 (43.47)^{f}	44.00 (41.54)^{f}	40.67 (39.60)^{e}	44.53 (39.60)
SEm±	0.59	0.95	0.84	1.00	0.96	0.87	1.13	1.08	1.15	0.93	-
CD (p=0.05)	1.80	2.89	2.56	3.04	2.92	2.64	3.44	3.28	3.47	2.82	-

Figures in parentheses are arc-sine transformed values; SEm± and CD were computed on arc-sine transformed data. Means followed by different superscript letters within a column differ significantly (DMRT, p=0.05).
DAI= Days after infestation

Table 3. Mean leaf damage rating (1-9 scale) due to *Spodoptera frugiperda* in maize at 10-day intervals

Treatment	10 DAI	20 DAI	30 DAI	40 DAI	50 DAI	60 DAI	70 DAI	80 DAI	90 DAI	100 DAI	Mean
T_1	2.40^{efg}	2.87^{efg}	3.40^{efg}	4.40^{ef}	4.93^{def}	4.33^{cdef}	3.60^{cdef}	3.04^{ef}	2.80^{ef}	2.40^{ef}	3.42
T_2	2.67^{e}	3.33^{bcde}	4.00^{cde}	4.73^{de}	5.20^{de}	4.53^{bcde}	3.93^{bcd}	3.20^{de}	2.98^{de}	2.53^{de}	3.71
T_3	2.27^{fgh}	2.73^{efgh}	3.13^{fgh}	3.93^{fgh}	4.07^{gh}	3.60^{gh}	2.60^{h}	2.33^{h}	2.20^{gh}	1.93^{gh}	2.88
T_4	2.53^{ef}	3.27^{bcdef}	3.73^{def}	4.33^{efg}	4.60^{fg}	4.00^{defg}	3.20^{fg}	2.87^{efg}	2.47^{g}	2.13^{fg}	3.31
T_5	3.07^{cd}	3.71^{abcd}	4.13^{bcd}	5.07^{bcd}	5.47^{bcd}	4.60^{abcd}	3.93^{bcde}	3.53^{cd}	3.13^{cd}	2.73^{d}	3.94
T_6	3.27^{bc}	3.98^{abc}	4.53^{abc}	5.47^{abc}	5.80^{abc}	4.93^{abc}	4.07b^{c}	3.80^{abc}	3.40^{c}	3.13^{bc}	4.24
T_7	3.47^{ab}	4.00^{ab}	4.67^{ab}	5.67^{ab}	5.93^{ab}	5.07^{ab}	4.40^{ab}	4.00^{ab}	3.73^{ab}	3.33^{ab}	4.43
T_8	3.73^{a}	4.26^{a}	4.80^{a}	5.86^{a}	6.13^{a}	5.20^{a}	4.73^{a}	4.06^{a}	3.91^{a}	3.46^{a}	4.62
SEm±	0.10	0.22	0.19	0.20	0.18	0.19	0.15	0.11	0.09	0.10	-
CD (p=0.05)	0.29	0.66	0.56	0.61	0.53	0.59	0.43	0.32	0.28	0.31	-

Means followed by different letters within a column differ significantly (DMRT, p=0.05). DAI= Days after infestation

chlorantraniliprole seed treatment, and the additional larvicidal effect of *Bt* foliar spray.

Natural enemy population

The natural enemy population was recorded in each plot at 10-day intervals from the date of first infestation until harvest (Table 4). Natural enemies such as Lynx spiders, *Coccinella transversalis, Coccinella septempunctata* and *Cheilomenes sexmaculata* were observed. The overall mean population of natural enemies was highest in T_3 (6.10 per plant), followed by T_1 (4.80), T_4 (4.70) and T_5 (4.03), and lowest in T_8 (untreated sole maize, 2.03), followed by T_7 (sole maize with farmer's practice, 2.50). At 10 DAI, the natural enemy population ranged from 2.00 to 6.67 per plant, highest in T_3 and lowest in T_8. Population increased progressively in all treatments, peaking at 50 DAI, where T_3 recorded the highest count (11.00), followed by T_4 (8.67) and T_1 (8.33), while T_7 and T_8 recorded the lowest counts (4.67 and 3.67, respectively). From 60 DAI onward, the natural enemy population declined in all treatments as the crop approached maturity, and no natural enemies were recorded at 90 and 100 DAI in any treatment, coinciding with maize senescence and harvest.

Table 4. Effect of treatments on the mean population of natural enemies in maize at 10-day intervals

Treatment	10 DAI	20 DAI	30 DAI	40 DAI	50 DAI	60 DAI	70 DAI	80 DAI	90 DAI	100 DAI	Mean
T_1	5.67 (2.48)^{ab}	6.67 (2.67)^{a}	7.00 (2.73)^{ab}	7.67 (2.86)^{b}	8.33 (2.96)^{ab}	6.33 (2.60)^{ab}	4.33 (2.20)^{ab}	2.67 (1.77)^{ab}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	1.21
T_2	4.00 (2.11)^{cd}	4.67 (2.26)^{bc}	5.33 (2.40)^{bc}	6.33 (2.61)^{cd}	6.67 (2.67)^{bc}	4.67 (2.26)^{bc}	3.00 (1.86)^{bcd}	2.00 (1.56)^{bc}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	1.39
T_3	6.67 (2.67)^{a}	7.67 (2.85)^{a}	9.00 (3.08)^{a}	10.33 (3.29)^{a}	11.00 (3.39)^{a}	8.33 (2.97)^{a}	4.67 (2.27)^{a}	3.33 (1.95)^{a}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	0.92
T_4	5.00 (2.35)^{bc}	6.00 (2.55)^{ab}	7.33 (2.79)^{ab}	8.33 (2.97)^{b}	8.67 (3.02)^{ab}	6.00 (2.54)^{b}	3.67 (2.04)^{abc}	2.67 (1.77)^{ab}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	1.21
T_5	3.67 (2.04)^{de}	4.67 (2.26)^{bc}	5.67 (2.48)^{bc}	7.00 (2.73)^{bc}	7.67 (2.85)^{b}	5.67 (2.48)^{b}	3.67 (2.04)^{abc}	2.33 (1.68)^{ab}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	1.63
T_6	3.00 (1.87)^{de}	3.67 (2.04)^{cd}	4.33 (2.18)^{cd}	5.67 (2.48)^{d}	6.33 (2.60)^{bc}	4.67 (2.26)^{bc}	2.67 (1.77)^{bc}	1.67 (1.46)^{bc}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	1.99
T_7	2.67 (1.77)^{ef}	3.33 (1.95)^{cd}	3.33 (1.93)^{d}	4.33 (2.20)^{c}	4.67 (2.27)^{cd}	3.33 (1.95)^{cd}	2.67 (1.77)^{cd}	1.00 (1.22)^{cd}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	2.20
T_8	2.00 (1.58)^{f}	3.00 (1.86)^{d}	3.00 (1.87)^{d}	3.67 (2.04)^{c}	3.67 (2.00)^{d}	2.67 (1.74)^{d}	2.00 (1.56)^{d}	0.67 (1.05)^{d}	0.00 (0.71)^{a}	0.00 (0.71)^{a}	2.29
SEm±	0.09	0.11	0.13	0.39	0.14	0.13	0.10	0.11	0.00	0.00	-
CD (p=0.05)	0.27	0.34	0.39	1.20	0.41	0.39	0.32	0.34	0.00	0.00	-

Figures in parentheses are transformed values. Means followed by different letters within a column differ significantly (DMRT, p=0.05). DAI= Days after infestation

Cob damage rating due to Spodoptera frugiperda

Mean cob damage rating (Table 5) ranged from 1.11 to 3.89 across treatments. T_3 recorded the lowest cob damage rating (1.11), statistically at par with T_4 (1.22), T1 (1.33) and T_2 (1.56), and significantly lower than the untreated treatments. The highest cob damage rating was observed in T8 (3.89), closely followed by T_7 (3.56).

Table 5. Effect of treatments on cob damage rating due to *Spodoptera frugiperda* in maize

Treatment	Mean cob damage rating
T_1	1.33^{ab}
T_2	1.56^{ab}
T_3	1.11^{a}
T_4	1.22^{a}
T_5	1.78^{b}
T_6	2.33^{c}
T_7	3.56^{d}
T_8	3.89^{d}
SEm±	0.16
CD (p=0.05)	0.49

Means followed by different superscript letters differ significantly (DMRT, p=0.05).

Yield and benefit cost ratio

Yield of maize and intercrop

The grain yield of maize varied significantly among treatments ranging from 27.78 q ha^{-1} in T_8 to 54.81 q ha^{-1} in T_3 (Table 6) and from 3.69 ha^{-1} to 6.14 q ha^{-1} in the intercrops. The highest yield of maize was recorded in T_3 at 54.81 q ha^{-1} which was significantly superior to all other treatments, followed by T_4 which yielded 43.70 q ha^{-1} and T_1 at 41.85 q/ha. In contrast the lowest yield was recorded in T_8 (sole maize without any treatment) at 27.78 q/ha which was closely followed by T_7 (sole maize with farmer's practice) at 29.26 q/ha.

Among the intercropped plots, the yields of legumes also varied in response to the protective treatment used. The maximum yield was recorded in T_3 (6.14 q ha^{-1}) followed by T_1 (5.25 q ha^{-1}) and T_5 (3.84 q ha^{-1}) for Ricebean. The maximum yield of Rajma was observed in T_4 (5.61 q ha^{-1}) followed by T_2 (5.23 q ha^{-1}) and T_6 (3.69 q ha^{-1}).

Benefit cost ratio

The benefit-cost ratio (Table 6) provides a single measure of economic efficiency by combining the net returns from each treatment with the entire cost of inputs, including labor. Among the treatments, the cultivation costs ranged from Rs. 34,595 ha^{-1} (T_7 and T_8) to Rs. 44,320 ha^{-1} (T_4). Similarly, net returns ranged from Rs. 139,353.91 ha^{-1} (T_3) to Rs. 20,960.55 ha^{-1} (T_8). T_3 had the highest benefit-to-cost ratio (1:3.17), followed by T_1 (1:2.24), T_2 (1:1.80), T_6 (1:1.41), T_7 (1:0.69), and T_8 (1:0.61).

Discussion

Percent plant infestation due to Spodoptera frugiperda

The characteristic rise of *S. frugiperda* infestation to a peak between 40 and 50 days after planting followed by a decline to harvest maturity probably reflects the vulnerability of the whorl-development stage to larval attack and the reduced host quality of the plant at the reproductive stage. The lower infestation levels recorded

Table 6. Cost effectiveness of various treatment combinations against *S. frugiperda* in maize during *kharif* 2025

Treatments	Yield of maize (q/ha)	Yield of intercrops (q/ha)	Cost of Cultivation (Rs./ha)	Total returns (Rs./ha)	Net Returns (Rs./ha)	Cost benefit Ratio
T_1	41.85	5.25	43701	146725.92	103024.92	2.36
T_2	39.63	5.23	44101	131555.55	87454.55	1.98
T_3	54.81	6.14	43920.2	183274.06	139353.91	3.17
T_4	43.70	5.61	44320.2	143481.47	99161.32	2.24
T_5	34.44	3.84	40985	114933.33	73948.33	1.80
T_6	31.48	3.69	41385	99814.81	58429.81	1.41
T_7	29.26	-	34595	58518.51	23923.51	0.69
T_8	27.78	-	34595	55555.55	20960.55	0.61

in legume-intercropped treatments compared to the sole crop and the relative superiority of the combined treatment of seed treatment + ricebean intercropping and *Bt* foliar spray (T_3) are consistent with the observations of Soujanya *et al*. (2024), who recorded significantly lower fall armyworm infestation in maize-legume intercropping systems compared to the sole maize from various agro-ecological zones of India, attributing the lower infestation to increased cropping system diversity, which disrupts the host-finding behavior of the pest and enhances the activity of natural enemies. The superiority of seed-treated plots over the non-treated ones echoes the findings of Behera and Ganiger (2024), who demonstrated the efficacy of chlorantraniliprole seed treatment against fall armyworm infestation. The relatively higher infestation levels in the plots intercropped with rajma compared to those intercropped with ricebean is consistent with the observations of Scheidegger *et al*. (2021) that common bean (*Phaseolus vulgaris* L.) was less repellent to fall armyworm larvae compared to other legumes.

Leaf damage rating due to Spodoptera frugiperda

Leaf damage rating followed a trend similar to percent plant infestation, peaking at 40-50 DAI before declining as the crop matured and became a less favourable pest environment. The consistently low leaf damage rating in T_3 is consistent with Soujanya *et al.* (2024), whose studies on legume-intercropped maize showed lower leaf damage due to disrupted host location and the mediating role of natural enemies. The lower leaf damage in seed-treated plots is consistent with Seye *et al.* (2023), who found that diamide insecticide seed treatment reduced the proportion of severely damaged plants by up to 86% at the early vegetative stage.

Natural enemy population

The natural enemy population gradually increased from 10 DAI reached its peak at 50 DAI and decreased as the crop matured. T_3 recorded the highest population of natural enemies during the entire experimental period, while untreated sole maize treatment (T_8) and farmer's practice maize treatment (T_7) registered the lowest population. The results are in line with Soujanya *et al*. (2024), who stated that intercropping resulted in a significant increase in the abundance of natural enemies primarily spiders and coccinellids compared to sole maize probably due to increased habitat complexity and the availability of alternative prey. The high predator population recorded in treatment T_3 coincides with the low fall armyworm infestation and supports the findings of Svobodová *et al*. (2017), who found that *Bt* maize-fed *S. frugiperda* did not negatively impact the development and survival of the predator *Harmonia axyridis*. Similarly, Sánchez-Hernández *et al*. (2021) explained the presence of alternative prey regulated the intraguild predation and contributed to effective pest control and Pierre *et al*. (2022) reported that companion crops provide suitable habitats for entomophagous arthropods by offering alternative prey and shelter, thereby augmenting their abundance and diversity. Agboyi *et al*. (2023) concluded that the *Bt*-based biopesticide had little adverse effect on the local parasitoid complex. Additionally, Mutyambai *et al*. (2022) recorded a significantly higher number of predators and parasitoids in legume-diverse maize than in monoculture maize.

Cob damage rating due to Spodoptera frugiperda

Cob damage rating followed a trend similar to the foliar infestation and leaf damage parameters, with the lowest rating in T_3 and the highest in untreated sole maize (T_8). This is consistent with Koffi *et al.* (2022), who reported significantly lower fall-armyworm ear-damage under farmers' field conditions in Ghana on farms treated with a *Bacillus thuringiensis*-based biopesticide compared with unsprayed controls. It also corroborates Kusi *et al.* (2024), who observed significantly less fall armyworm cob damage in soybean-intercropped maize than in sole maize, and Yuya *et al.* (2025), who reported lower fall armyworm ear-damage scores under maize-legume intercropping than sole maize in Ethiopia.

Yield and benefit cost ratio

Yield of maize and intercrop

The yield advantage of T_3 and T_4 over the seed treatment only (T_1 and T_2) and intercrop only (T_5 and T_6) indicates an additive effect of combining a systemic seed treatment with a biopesticide foliar spray on a legume diversified background. These results indicate that maize cultivated alongside legumes consistently surpassed sole maize, and

the productivity benefit was further improved when intercropping was paired with seed treatment and foliar application of *Bacillus thuringiensis*. The findings of this study align closely with those of Agbor *et al*. (2023), who found that maize intercropped with cowpea and dwarf bean, along with the use of botanical insecticides, resulted in significantly greater grain yields compared to sole maize. They attributed this enhancement to reduced insect damage and the additional nitrogen provided by leguminous plants via biological nitrogen fixation, which fostered improved crop growth and productivity. The current results are also in line with Koffi *et al*. (2022), who found that maize treated with a *Bacillus thuringiensis* based biopesticide yielded significantly more grain than untreated plants during natural fall armyworm infestation. Likewise, the results support those of Soujanya *et al*. (2024), who showed that intercropping maize with legumes significantly lowered fall armyworm infestations, boosted the presence of natural predators, and improved maize grain yield in comparison to sole maize farming. They determined that increased crop diversity enhanced the ecological control of fall armyworm while also boosting the productivity and stability of the agricultural system.

Benefit cost ratio

The economic analysis revealed considerable variation among the treatments with respect to cost of cultivation, gross returns, net returns and benefit-cost (B:C) ratio, indicating that maize and legume intercropping integrated with suitable pest management practices substantially enhanced the profitability of maize production. The present finding are in close agreement with those of Soujanya *et al*. (2024), who reported that maize and legume intercropping significantly reduced fall armyworm infestation while increasing maize yield, overall system productivity and economic returns compared with sole maize cultivation. The present results are further supported by Agbor *et al*. (2023), who found that maize and legume intercropping combined with environmentally friendly pest management practices significantly improved maize yield and farm profitability. The diversified cropping system not only provides additional income through intercrop harvest but also contribute to suppression of insect pest populations and thereby enhancing the economic sustainability of maize production.

Conclusion

The fall armyworm infestation levels and leaf injury in maize increased up to 40–50 days after planting and declined thereafter. The highest pest attack as well as the lowest yield and the benefit cost ratio was observed in the sole maize system, and intercropping of maize with ricebean or rajma significantly reduced pest incidence. The combined use of chlorantraniliprole seed treatment and *Bt* foliar spray enhanced the suppression of fall armyworms and their damage to maize leaves and cobs compared to untreated intercropped ones. The lowest pest attack, leaf injury, and cob damage, along with the highest natural enemy abundance, yield and benefit cost ratio were found when maize was intercropped with ricebean, where its seeds were treated with chlorantraniliprole and the plants were sprayed with *Bt* at 25–30 days after germination. It may be concluded that legume intercropping of maize with appropriate pest control measures could be one of the key components of integrated pest management against fall armyworm.

Acknowledgements

The authors gratefully acknowledge the Central Agricultural University, Imphal, for providing the experimental facilities used in this study.

Ethics and conflict of interest

Ethical approval/clearance: The research was conducted ethically and in compliance with relevant guidelines and regulations.

Informed consent: This study did not involve human participants.

Animal welfare: No animal use was involved in the study.

Conflict of interest: The authors declare no conflict of interest.

References

Agbor, D. T., Eboh, K. S., Sama, D. K., Teche, L. M., Tanyi, G. T. & Nkongho, R. N. (2023). Maize-legume intercropping and botanical piper mitigating effect on pest populations while enhancing the yield of maize. *J. Nat. Pestic. Res.,* **6**: 100060.

Agboyi, L. K., Nboyine, J. A., Asamani, E., Beseh, P., Badii, B. K., Kenis, M. & Babendreier, D. (2023). Comparative effects

of biopesticides on fall armyworm management and larval parasitism rates in northern Ghana. *Journal of Pest Science*, **96**: 1417–1428. https://doi.org/10.1007/s10340-023-01590-z

Behera, R. K., K, M. M. & Ganiger, P. C. (2024). Seed treatment with insecticides - a potential option against fall army worm *Spodoptera frugiperda* in maize. *Indian Journal of Entomology*, **86**(3): 845–849. https://doi.org/10.55446/IJE.2023.1329

Dass, S., Jat, S. L., Chikkappa, G. K. & Parihar, C. M. (2018). Crop production management to climate change. In: *Food Security and Climate Change* (Yadav, S. S., Redden, R. J., Hatfield, J. L. & Ebert, A. W., eds). Wiley-Blackwell, Hoboken, New Jersey. pp. 251–287.

Davis, F. M., Ng, S. S. & Williams, W. P. (1992). Visual rating scales for screening whorl-stage corn for resistance to fall armyworm. *Mississippi Agricultural and Forestry Experiment Station Technical Bulletin*, **186**: 1–9.

Directorate of Economics and Statistics (2024). Agricultural Statistics at a Glance. DA&FW, Government of India, New Delhi.

Gomez, K. A. & Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research* 2nd edn. pp. 680. John Wiley and Sons, New York.

Government of Manipur, Department of Agriculture (2023). Annual Administration Report 2022–2023. Government of Manipur. https://agrimanipur.gov.in

Hailu, G., Niassy, S., Zeyaur, K. R., Ochatum, N. & Subramanian, S. (2018). Maize-legume intercropping and push-pull for management of fall armyworm, stemborers, and striga in Uganda. *Agronomy Journal*, **110**(6): 2513–2522. https://doi.org/10.2134/agronj2018.02.0110

Koffi, D., Kyerematen, R., Osae, M., Amouzou, K. & Eziah, V. Y. (2022). Assessment of *Bacillus thuringiensis* and emamectin benzoate on the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) severity on maize under farmers' fields in Ghana. *International Journal of Tropical Insect Science*, **42**(2): 1619–1626. https://doi.org/10.1007/s42690-021-00683-5

Kusi, F., Nboyine, J. A., Adjebeng-Danquah, J., Agrengsore, P., Seidu, A., Quandahor, P., Sugri, I., Adazebra, G. A., Agyare, R. Y., Asamani, E., Kwabena, J. Y., Otchere-Darko, E. & Etwire, P. M. (2024). Effect of insecticides and intercropping systems on fall armyworm (*Spodoptera frugiperda* (J. E. Smith)) infestations and damage in maize in northern Ghana. *Crop Protection*, **186**: 106909. https://doi.org/10.1016/j.cropro.2024.106909

Malhotra, S. K. (2017). Diversification in utilization of maize and production. In: *Proceedings of Gyan Manthan Conference: Perspective of Maize Production and Value Chain* A Compendium, Vol. 5. pp. 49–57.

Mallapur, C. P., Naik, A. K., Hagari, S., Prabhu, S. T. & Patil, R. K. (2018). Status of alien pest fall armyworm, *Spodoptera frugiperda* (J. E. Smith) on maize in northern Karnataka. *Journal of Entomology and Zoology Studies*, **6**(6): 432–436.

Mutyambai, D. M., Niassy, S., Calatayud, P. A. & Subramanian, S. (2022). Agronomic factors influencing fall armyworm (*Spodoptera frugiperda*) infestation and damage and its co-occurrence with stemborers in maize cropping systems in Kenya. *Insects*, **13**(3): 266. https://doi.org/10.3390/insects13030266

Pierre, J. F., Latournerie-Moreno, L., Garruña, R., Jacobsen, K. L., Laboski, C. A. M., Us-Santamaría, R. & Ruiz-Sánchez, E. (2022). Effect of maize-legume intercropping on maize physio-agronomic parameters and beneficial insect abundance. *Sustainability*, **14**(19): 12385. https://doi.org/10.3390/su141912385

Sánchez-Hernández, C. V., Desneux, N., Bao-Fundora, L. & Ramirez-Romero, R. (2021). Alternative extraguild prey modifies focal extraguild prey consumption and parasitism but not intraguild predation intensity. *Biological Control*, **153**: 104475. https://doi.org/10.1016/j.biocontrol.2020.104475

Scheidegger, L., Niassy, S., Midega, C., Chiriboga, X., Delabays, N., Lefort, F., Zürcher, R., Hailu, G., Khan, Z. & Subramanian, S. (2021). The role of *Desmodium intortum*, *Brachiaria* sp. and *Phaseolus vulgaris* in the management of fall armyworm *Spodoptera frugiperda* (JE Smith) in maize cropping systems in Africa. *Pest Management Science*, **77**: 2350–2357. https://doi.org/10.1002/ps.6261

Seye, D., Silvie, P. & Brévault, T. (2023). Effect of maize seed treatment on oviposition preference, larval performance and foliar damage of the fall armyworm. *Journal of Applied Entomology*, **147**(5): 299–306. https://doi.org/10.1111/jen.13114

Sharanabasappa, Kalleshwaraswamy, C. M., Poorani, J., Maruthi, M. S., Pavithra, H. B. & Diraviam, J. (2019). Natural enemies of *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), a recent invasive pest on maize in South India. *Florida Entomologist*, **102**(3): 619–623. https://doi.org/10.1653/024.102.0335

Soujanya, P. L., VaniSree, K., Giri, G. S., Mahadik, S., Jat, S. L., Sekhar, J. C. & Jat, H. S. (2024). Intercropping in maize reduces fall armyworm *Spodoptera frugiperda* (JE Smith) infestation, supports natural enemies, and enhances yield. *Agriculture, Ecosystems & Environment*, **373**: 109130. https://doi.org/10.1016/j.agee.2024.109130

Svobodová, Z., Burkness, E. C., Skoková Habuštová, O. & Hutchison, W. D. (2017). Predator preference for Bt-fed *Spodoptera frugiperda* (Lepidoptera: Noctuidae) prey: implications for insect resistance management in Bt maize seed blends. *Journal of Economic Entomology*, **110**(3): 1317–1325. https://doi.org/10.1093/jee/tox098

Vatta, K., Arora, K., Kumar, S., Bhoi, P. B. & Adhale, P. (2023). Commodity Outlook Report: Maize. Department of Economics and Sociology, Punjab Agricultural University, Ludhiana.

Yuya, A. I., Degaga, E. G., Degefu, D. T. & Bekele, G. D. (2025). Impact of maize-legume intercropping systems on fall armyworm, *Spodoptera frugiperda* (JE Smith) infestation levels and natural enemy complex. *International Journal of Tropical Insect Science*, **45**: 989–1005. https://doi.org/10.1007/s42690-025-01487-7